Impact of Total and Effective Imperviousness on Runoff Prediction

Sahoo Sanat Nalini and P. Sreeja

Abstract Urbanization in a broad sense means increase in imperviousness and thus putting more obstruction to free flow of water into the ground surface. The most commonly used measure of imperviousness is total impervious area (TIA), which is a measure of the area that resists the rain water to infiltrate the down soil, whereas effective impervious area (EIA) is that fraction of TIA that has a direct hydraulic connection to the downstream drainage. Imperviousness being an important parameter in most of the hydrologic models has brought considerable attention in recent years among the researchers community. Hence, the need arises to evaluate the degree of accuracy of using TIA or EIA in hydrologic modeling. Toward this end, the current study presents a comparison between the predicted runoff of an Indian catchment using TIA and EIA in a hydrologic model and hence the better predictor has been found out.

Keywords Urbanization · Total impervious area · Effective impervious area · Hydrologic modeling

1 Introduction

Imperviousness being a direct measure of urbanization (Snyder et al. 2005) information, it is very much essential for urban hydrology and watershed management. Imperviousness may be of two types, directly connected (effective impervious area i.e. EIA) and indirectly connected (non effective) impervious areas. Together they constitute total impervious area (TIA). EIA is that portion of TIA that has a direct hydraulic connection to the downstream drainage network. Many times due to lack of proper and accurate data TIA has been used as EIA in hydrologic models. Many

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studies (Han and Burian 2009; Ravagnani et al. 2009) have been reported that emphasize the effect of imperviousness on changing hydrological characteristics of a watershed. However, studies need to be addressed to access the capability of either type of imperviousness to predict the runoff accurately. Toward this end, the current study compares the TIA-predicted runoff and EIA-predicted runoff for an Indian catchment. In thistudy, TIA has been estimated by a combined approach of remote sensing and GIS. EIA has been estimated (Alley and Veenhuis 1983) using an empirical equation. The estimated imperviousnesses are further utilized to predict the runoff of the watershed and thus a comparison between both are presented.

2 Study Area

The study area, Guwahati as depicted in Fig. 1 is a part of Kamrup District in Assam (North East India), and is situated between 26° 4′ 45″ and 26° 13′ 25″ North Latitude and between 91° 34′ 25″ and 91° 52′ 00″ East Longitude. Located on the Bank of River Brahmaputra, it is the largest commercial, industrial, and educational centre of the north east India and a rapidly expanding urban city. The city is situated on an undulating plane of varying altitude of 47.0 to 55.5 m above Mean Sea Level (MSL). The southern and eastern sides of the city are surrounded by hillocks. Apart from the hilly tracts, swampy/marshy lands and water bodies cover a considerable portion of the city. In this study, the city area has been divided into seven watersheds. The methodology used in this study is demonstrated with respect to one watershed (*Silsako* watershed).

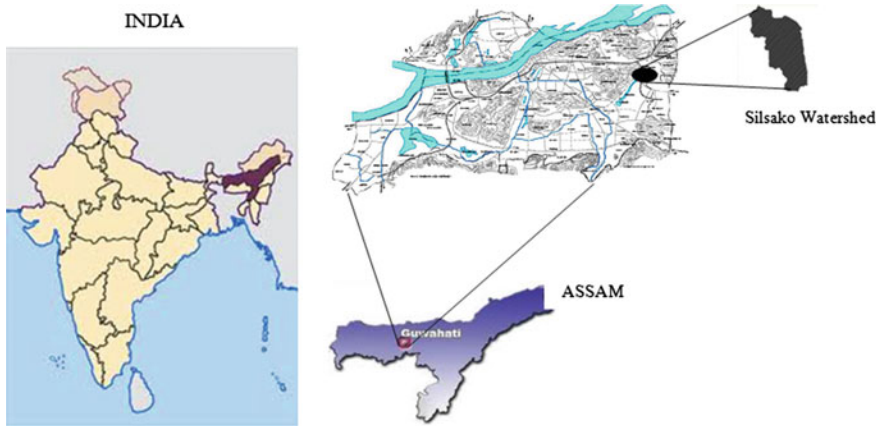

Fig. 1 Location of *Silsako* watershed of Guwahati city

3 Methodology

In the present study, a methodology is followed which combines the GIS and remote sensing technologies (Ravagnani et al. 2009) to obtain the imperviousness of the study site. The image (LISS4 image of Guwahati for 2006) has been classified into seven basic classes namely built-up area, water body, forest, scrub land, agricultural land, swampy/marshy land, and grass land. For classification process, training areas having good separability values (Han and Burian 2009) were selected at various locations of the image. The built-up area estimated from the classification of the imageries that includes the building rooftops and the transportation networks which are collectively called as TIA. TIA includes both effective impervious area (EIA) and noneffective impervious area (NEIA). The most commonly used measure of imperviousness is TIA which is a measure of the area that prevents water infiltration into the soil. Since direct determination of EIA is a data and time-demanding process, an indirect methodology has been followed here to calculate EIA. The TIA estimated from the classified image was then converted to EIA by an empirical relationship given in Eq. (1) (Alley and Veenhuis 1983).

$$\mathrm{EIA} = 0.15\,\mathrm{TIA}^{1.41} \quad (1)$$

4 Runoff Simulation of Watersheds

In this study, SWMM is used as the hydrologic model because of its success in modeling the urban watersheds (Delleur 2003; Spry and Zhang 2006). SWMM developed by EPA (Environmental Protection Agency, USA) (Rossman 2005) is a dynamic rainfall runoff simulation model that computes runoff originating primarily from urban areas from single or continuous events (Huber and Dickinson 1988). It consists of several different blocks (Wang and Altunkaynak 2011) to be simulated separately. Blocks used in the current study are the runoff block for runoff estimation and transport block for routing of the estimated runoff. Infiltration has been modeled by Green–Ampt method. The physical characteristics such as area, width, and slope of the sub-watersheds are determined from ArcGIS 9.3.1. The output from runoff block is used as the input for the subsequent transport block, which models the drainage channels as a series of geometrical hydraulic “elements”, that are nodes or conduits. All the conduit properties and the node properties were derived from the available drainage network details. To best capture the spatial variability of the catchment parameters, the study site is further segregated into 22 sub-watersheds. Runoff is simulated at the outlet of each of the sub-watersheds using the above said methodology and then dynamic wave routing is employed to route the flow in the drains to the common outlet (Silsakolake) of the catchment. A continuous simulation has been performed here due to lack of short interval rainfall data.

5 Analysis and Results

Due to lack of short interval rainfall data, a continuous hydrologic modeling has been performed here. Continuous hydrologic modeling also synthesizes hydrologic processes and phenomena (i.e., synthetic responses of the basin to a number of rain events and their cumulative effects) over a longer time period that includes both wet and dry conditions (Chu and Steinman 2009).

Figure 2 shows the variation of runoff in monsoon seasons from the month of June to September for the year 2006 due to TIA of the study area. It can be noticed that comparatively large flood events are found to hit the study area more frequently. The peak runoff in 2006 was observed to be 36.3 m^3/s on 11th June from a rainfall intensity of 4.24 mm/h.

Figure 3 shows the simulated runoff in monsoon seasons for the year 2006 due to EIA. The peak runoff in 2006 was 26.15 m^3/s on 11th June from a rainfall intensity of 4.24 mm/h.

Figure 4 shows a comparison between the runoff predicted by TIA and EIA of the study area. It is clear from the figure that the TIA predicts 38.9 % more runoff in the catchment than it is predicted by EIA. However, it can be mentioned here that the time to peak remains the same for both the cases and only the peak is magnified. However, the results need to be refined using any direct methodology of EIA determination that can be employed to predict runoff.

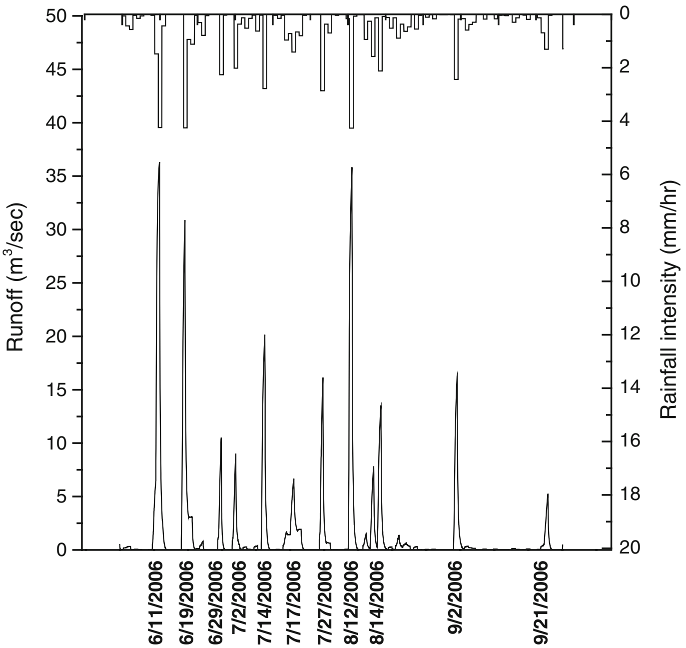

Fig. 2 Runoff simulated in monsoon season taking TIA as imperviousness

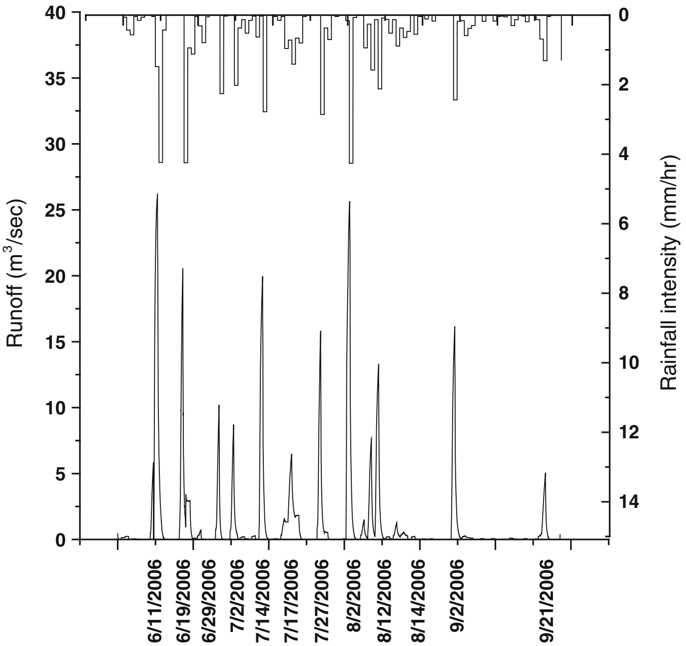

Fig. 3 Runoff simulated in monsoon season taking EIA as imperviousness

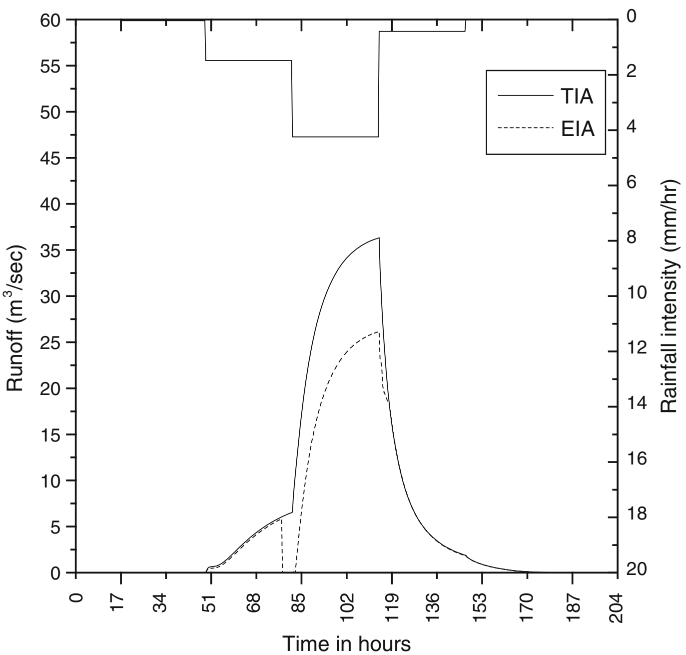

Fig. 4 Runoff predicted due to TIA and EIA

6 Conclusion

Being the discharge data unavailable to check the accuracy of the model, a comparison has been done for simulated runoffs by TIAs and EIAs. Peak runoff in 2006 is overestimated by 38.9 % if TIA is used in the model instead of EIA. However, the result can be further modified by feeding short duration rainfall data as input file.

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